The response of a neutron rem counter to thermal, to intermediate-energy, and to fast neutrons

Majborn, B.

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Benny Majborn
Risø National Laboratory
Roskilde, Denmark

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Abstract

A neutron rem counter (Studsvik type 2202D) was calibrated at a number of neutron energies during a technical seminar on neutron dosimetry in radiation protection sponsored by the Commission of the European Communities and held at the Physikalisch-Technische Bundesanstalt in Braunschweig.

The rem counter was calibrated using

1) monoenergetic neutrons of eight different energies between 100 keV and 19 MeV produced by means of an accelerator,
2) neutrons from three radioactive neutron sources (Ra-Be, Am-Be and ^{252}Cf), and
3) a thermal-neutron beam and two filtered neutron beams (2 and 24.5 keV, respectively) from a reactor.

The results show that the sensitivity of the rem counter follows the "ICRP rem curve" within about $\pm$ 20 % at neutron energies between 250 keV and 5 MeV. However, at neutron energies below 100 keV and above 10 MeV the sensitivity deviates significantly from the "ICRP rem curve". When calibrated at, say, 1 MeV, the rem counter will overestimate the dose equivalent in radiation fields where a significant portion of the dose equivalent is due to neutrons of energies between 100 eV and 100 keV, and it will underestimate the dose equivalent from thermal neutrons and from neutrons of energies above 10 MeV.

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INIS Descriptors

CALIBRATION
DOSE EQUIVALENTS
ENERGY DEPENDENCE
FAST NEUTRONS
INTERMEDIATE NEUTRONS
NEUTRON DETECTORS
NEUTRON DOSIMETRY
RESPONSE FUNCTIONS
SENSITIVITY
THERMAL NEUTRONS

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1. INTRODUCTION

A neutron rem counter was calibrated at a number of neutron energies during a technical seminar on neutron dosimetry in radiation protection sponsored by the Commission of the European Communities and held at the Physikalish-Technische Bundesanstalt (PTB) in Braunschweig in April 1977.

The rem counter was a Studsvik neutron rem counter type 2202D(1). The detector is a BF_3 proportional counter surrounded by polyethylene and boron plastic. The dimensions are shown in Fig. 1. The rem counter was irradiated from the side (i.e. at right angles to the axis of symmetry) during all irradiations.

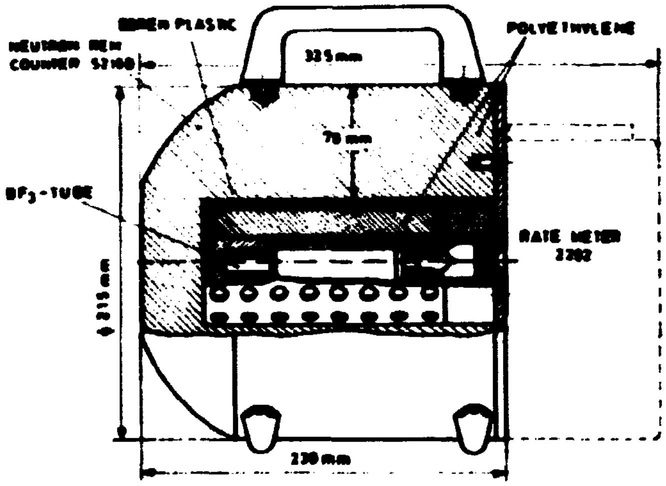

Fig. 1.

Sketch of the Studsvik neutron rem counter type 2202D (from ref. (1)).

The rem counter was calibrated using:

1) monoenergetic neutrons of eight different energies between 100 keV and 19 MeV produced by means of an accelerator,

2) neutrons from three radioactive neutron sources (Ra-Be, Am-Be and ^{252}Cf), and

3) a thermal-neutron beam and two filtered neutron beams (2 and 24.5 keV, respectively) from a reactor.

The following quantities are reported for each neutron energy:

a) The response, R, defined as the number of counts per unit fluence. R is given in cm^2 (counts per neutron per cm^2).

b) The calibration factor, N, defined as the correct value of the quantity to be measured (the dose equivalent) divided by the value indicated by the instrument (the number of counts).

$$N = \frac{h_\phi}{R},$$

where h_ϕ is the fluence-to-dose-equivalent conversion factor as recommended by the ICRP (2).
N is given in $J \cdot kg^{-1}$ (the number of $J \cdot kg^{-1}$ per count).

c) The sensitivity, S, defined as the count rate (in counts per second) divided by the dose equivalent rate (in mrem per hour).

$$S = (3.6 \times 10^8\ N)^{-1}\ s^{-1} \cdot mrem^{-1} \cdot h,$$

when N is given in $J \cdot kg^{-1}$.

The results are reported in sections 2,3 and 4 and summarized in section 5.

2. ACCELERATOR IRRADIATIONS

Monoenergetic neutrons were obtained from a Van de Graaff accelerator using the $^7Li(p,n)$, $T(p,n)$, $D(d,n)$ and $T(d,n)$ reactions. The rem counter was irradiated at the following neutron energies: 100, 250 and 570 keV, 1, 2.5, 5, 15.5 and 19 MeV.

The distance between the target and the geometrical centre of the detector was 1 m during most irradiations. However, at 25o keV, 1 MeV and 15,5 MeV, the count rate was measured as a function of distance between target and detector centre, using five distances between 0.8 and 1.6 m. These measurements indicated that the "background" was negligible at a distance of 1 m at all three energies, so the results reported in the following (Table I) have not been corrected for the contribution to the count rate from room- and air-scattered neutrons.

The fluence at the position of the detector (1 m from the target) varied from $2.3 \times 10^5\ cm^{-2}$ to $5.5 \times 10^5\ cm^{-2}$, the irradiation time varied from 106 to 380 seconds, and the dose equivalent rate varied from 7.7×10^{-8} W · kg^{-1} (28 mrem · h^{-1}) to 2.1×10^{-6} W · kg^{-1} (750 mrem · h^{-1}).

The results are summarized in Table I. The uncertainties assigned to the response values refer to the uncertainties estimated by the PTB for the neutron fluence values at a confidence level of 68 % (3). The statistical standard error on the total number of counts registered by the rem counter was less than 0.5 % at all the eight neutron energies.

Table I

Measured response of the Studsvik 2202D rem counter to monoenergetic neutrons from a Van de Graaff accelerator.

Neutron energy MeV	Conversion factor J · kg^{-1} · cm^2	Response R cm^2	Calibration factor, N J · kg^{-1}	Sensitivity S s^{-1} · mrem^{-1} · h
0.100	5.78×10^{-11}	0.103 ± 0.006	5.6×10^{-10}	4.9
0.250	1.18×10^{-10}	0.176 ± 0.011	6.7×10^{-10}	4.1
0.570	2.18×10^{-10}	0.290 ± 0.015	7.5×10^{-10}	3.7
1.0	3.27×10^{-10}	0.409 ± 0.020	8.0×10^{-10}	3.5
2.5	4.01×10^{-10}	0.492 ± 0.030	8.2×10^{-10}	3.4
5.0	4.08×10^{-10}	0.410 ± 0.021	10.0×10^{-10}	2.8
15.5	4.18×10^{-10}	0.222 ± 0.011	18.9×10^{-10}	1.5
19.0	4.22×10^{-10}	0.282 ± 0.034	15.0×10^{-10}	1.9

3. RADIOACTIVE NEUTRON SOURCE IRRADIATIONS

The rem counter was irradiated with neutrons from three radioactive neutron sources:

a Ra-Be (α,n) source with a source strength of $2.045 \times 10^6 \times (1 \pm 0.014)$ s^{-1},
an ^{241}Am-Be (α,n) source with a source strength of $3.14 \times 10^6 \times (1 \pm 0.02)$ s^{-1},
and a ^{252}Cf (spontaneous fission) source with a source strength of $6.92 \times 10^6 \times (1 \pm 0.023)$ s^{-1} on April 16, 1977.

The rem counter was irradiated with a distance of 1 m between the centre of the source and the geometrical centre of the rem counter. At this distance 8 % of the generated count rate was due to room- and air-scattered neutrons. For each source, the total number of counts was registered for a number of consecutive counting periods with a duration of 1000 seconds.

The results are summarized in Table II. The uncertainties assigned to the response values refer to the uncertainties given by the PTB for the values of the source strengths (3). The statistical standard error on the total number of counts registered by the rem counter was less than 0.3 % at all the three source irradiations. The uncertainties of the values of the conversion factors for the neutron spectra of the three sources are estimated at 10 % at a confidence level of 68 % (3).

Table II

Measured response of the Studsvik 2202D rem counter to neutrons from three different radioactive sources.

Source	Conversion factor $J \cdot kg^{-1} \cdot cm^2$	Response R cm^2	Calibration factor, N $J \cdot kg^{-1}$	Sensitivity S $s^{-1} \cdot mrem^{-1} \cdot h$
Ra-Be	3.0×10^{-10}	0.363 ± 0.005	8.3×10^{-10}	3.4
Am-Be	3.7×10^{-10}	0.386 ± 0.008	9.6×10^{-10}	2.9
^{252}Cf	3.4×10^{-10}	0.394 ± 0.009	8.6×10^{-10}	3.2

4. REACTOR BEAM IRRADIATIONS

Beam irradiations were carried out at the Forschungs- und Messreaktor Braunschweig (FMRB). A thermal-neutron calibration beam and two filtered neutron beams with a scandium filter (2 keV) and an iron/aluminium filter (24.5 keV) respectively were used. The thermal-neutron beam facility has been described by Kluge and Knauf (4) and the filtered beam facilities have been described by Alberts and Knauf (5).

In order to reduce the influence of the fast neutron background, extra background measurements were made with each of the filtered beams passing through an additional filter that attenuated the main peak, leaving the rest of the spectrum almost unchanged. As "subtraction filter" material manganese was used for the scandium-filtered beam and titanium for the iron/aluminium-filtered beam (5).

The beam cross sections were smaller than the dimensions of the rem counter, so it was necessary to move the rem counter in a plane at right angles to the beam axis and irradiate it point by point in order to simulate a broad beam irradiation. The calculation of the response when using this procedure has been discussed in ref. (5).

The neutron current density in the plateau of the beam was 1.0×10^7 cm^{-2} s^{-1} for the thermal-neutron beam, 1.5×10^3 cm^{-2} s^{-1} for the 2 keV beam, and 2.0×10^3 cm^{-2} s^{-1} for the 24.5 keV beam. The data for the filtered beams refer to the "difference" beams. The beam diameters (the full width at half maximum) were 3.7 cm for the thermal beam, 13.5 cm for the 2 keV beam, and 8.5 cm for the 24.5 keV beam.

Since a large number of detectors had to be irradiated during a limited period of time, a complete scanning of the Risø rem counter was made only at the 2 keV beam. However, another rem counter of the same type (Studsvik 2202D) from CEN/SCK, Mol, was scanned at all the three reactor beams. From a comparison of the results obtained with the two rem counters, the response of the Risø rem counter was thus calculated both for thermal neutrons and for 24.5 keV neutrons.

At the 2 keV beam, the Risø rem counter was irradiated at 25 positions making up a 32 x 32 cm pattern with 8 cm steps. At each position an irradiation was made both with and without the additional manganese "subtraction filter". The duration of each irradiation was 100 seconds.

At the 24.5 keV beam, only a central point irradiation was made (with and without the additional titanium filter). However, the broad-beam response of the Risø rem counter was calculated from a comparison with the results obtained by Van Bosstraeten for the Mol rem counter (6).

At the thermal-neutron beam, a horizontal scanning was made along the axis of the rem counter. The count rate for thermal neutrons was obtained as the difference between the count rates registered during irradiation without and with a cadmium cover, respectively. The count rate as a function of position measured during the horizontal scanning is shown in Fig. 2. Within the range of $8 \text{ cm} < x < 20$ cm (Fig. 2), the influence of the neutrons scattered by the cable inlet can be seen. Similar curves showing count rate as a function of position have been reported by Matzke (7) for a rem counter that is essentially of the original Andersson and Braun design (8).

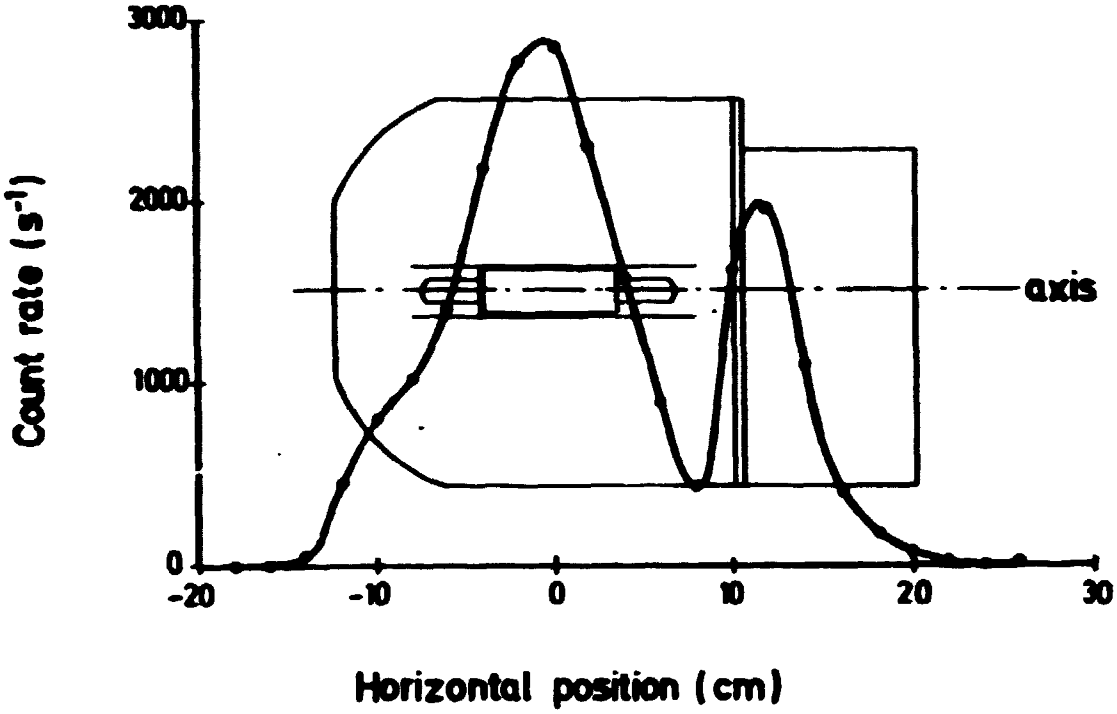

Fig. 2

Count rate of Studsvik 2202D rem counter as a function of position for horizontal scanning along the axis with a narrow thermal-neutron beam. The rem counter was irradiated at right angles to the axis. The beam diameter was 3.7 cm (full width at half maximum).

Also for thermal neutrons the broad-beam response of the Risø rem counter was calculated from a comparison with the results obtained by Van Bosstraeten for the Mol rem counter(6).

The results obtained using the three reactor beams are summarized in Table III.

Table III

Response of the Studsvik 2202D rem counter to reactor beam neutrons.

Neutron energy	Conversion factor $J \cdot kg^{-1} \cdot cm^2$	Response R cm^2	Calibration factor, N $J \cdot kg^{-1}$	Sensitivity S $s^{-1} \cdot mrem^{-1} \cdot h$
Thermal	1.07×10^{-11}	0.0067*)	16.0×10^{-10}	1.7
2 keV	0.98×10^{-11}	0.079**)	1.2×10^{-10}**)	22**)
24.5 keV	1.85×10^{-11}	0.081*)	2.3×10^{-10}	12

*) calculated from a comparison with the results obtained by Van Bosstraeten for the Mol rem counter (6).

**) preliminary values, see text.

For the thermal-neutron beam, the uncertainty of the neutron current density value is estimated to ± 3 % at a confidence level of 68 % (3), and the uncertainty of the response value is estimated to ± 4.5 % at a confidence level of 68 % (9).

For the filtered beams, the uncertainties are considerably higher. The uncertainty of the neutron current density values has been roughly estimated to be of the order of 30 % for the 2 keV beam and 20 % for the 24.5 keV beam (5). Furthermore, a recent evaluation at the PTB of the ratio of count rates for several detectors in the 2 keV beam with and without the difference filter has indicated a still significant high-energy background in the 2 keV difference beam (3). Because of the higher response of rem counters to higher energy neutrons, this will influence the response R obtained from the evaluation procedure applied. Very roughly, it is estimated that the response R given in Table III for the 2 keV beam is too high by a factor of 2 (3). The contribution to the response from the higher energy neutrons will be further investigated at the PTB (3). At the moment the values of the response R, the calibration factor N, and the sensitivity S, given in Table III for 2 keV neutrons, should be considered as preliminary. If R is reduced by a factor of about 2 at 2 keV, and the calibration factor N and the sensitivity S are changed accordingly, the respective values of N and S will be approximately equal at 2 and 24.5 keV.

5. DISCUSSION AND CONCLUSION

The results are summarized in Table IV. They show that the sensitivity of the rem counter deviates from the "ICRP rem curve" (2), particularly at neutron energies below 100 keV and above 10 MeV.

When calibrated at, say, 2.5 MeV, the rem counter will overestimate the dose equivalent significantly at intermediate neutron energies, i.e. from about 100 eV to 100 keV. As mentioned in section 4, the preliminary value of the sensitivity reported at 2 keV may be too high by a factor of roughly 2, so the sensitivity may be approximately the same at 2 and at 24.5 keV, i.e. a factor of 3 to 4 higher than the sensitivity at 2.5 MeV. Similar results for 2 and 24.5 keV neutrons have been reported by Alberts and Knauf (5) for an Andersson and Braun rem counter, type REM/N, manufactured by 20th Century Electronics. On the other hand, the rem counter will underestimate the dose equivalent by a factor of about 2 for thermal neutrons and for neutrons of energies 15.5 and 19 MeV.

Hankins (10) reported a measured oversensitivity of a rem counter (similar to that calibrated by Alberts and Knauf) amounting to a factor of about 4 at 25 keV and somewhat less at 2 keV. His irradiations were made at the beam facilities of the NBS reactor in Washington D.C. Hankins used the conversion factors from fluence to dose equivalent recommended in NCRP Report No. 38 (11). If the fluence to dose equivalent conversion factors recommended by the ICRP (2) are used (as in the present report), the rem counter responses measured by Hankins at 2 and 25 keV correspond to an oversensitivity amounting to a factor of about 3 at both energies.

Harvey, Lavender and Thompson (12) calibrated two rem counters with a neutron source emitting neutrons in a broad spectrum around 0.5 keV. They normalized the response per dose equivalent rate to unity at 2 MeV, and found an oversensitivity (around 0.5 keV) amounting to a factor of 2.1 for a Studsvik type 2202D rem counter and a factor of 1.5 for a 20th Century Electronics type REM/N rem counter.

All the results imply that a neutron rem counter of the Andersson and Braun type, when calibrated at, say, 1 MeV, will overstimate the dose equivalent in radiation fields where a significant portion of the dose equivalent is due to neutrons of energies between 100 eV and 100 keV, and that it will underestimate the dose equivalent from thermal neutrons and from neutrons of energies above 10 MeV.

Table IV

Summary of response, calibration factor and sensitivity as a function of neutron energy for the neutron rem counter Studsvik type 2202D.

Neutron energy	Response R cm^2	Calibration factor, N $J \cdot kg^{-1}$	Sensitivity S $s^{-1} \cdot mrem^{-1} \cdot h$	Relative sensitivity x)
Thermal	0.0067	16.0×10^{-10}	1.7	0.50
2 keV	0.079 xx)	1.2×10^{-10} xx)	22 xx)	6.5 xx)
24.5 keV	0.081	2.3×10^{-10}	12	3.5
100 -	0.103	5.6×10^{-10}	4.9	1.4
250 -	0.176	6.7×10^{-10}	4.1	1.2
570 -	0.290	7.5×10^{-10}	3.7	1.1
1 MeV	0.409	8.0×10^{-10}	3.5	1.0
2.5 -	0.492	8.2×10^{-10}	3.4	1.0
5 -	0.410	10.0×10^{-10}	2.8	0.82
15.5 -	0.222	18.9×10^{-10}	1.5	0.44
19 -	0.282	15.0×10^{-10}	1.9	0.56
Ra-Be	0.363	8.3×10^{-10}	3.4	1.0
Am-Be	0.386	9.6×10^{-10}	2.9	0.85
^{252}Cf	0.394	8.6×10^{-10}	3.2	0.94

x) normalized to unity at 2.5 MeV

xx) preliminary values, cf. section 4.

6. ACKNOWLEDGEMENTS

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